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To cite this article: A Yu Melnikov *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **971** 042067

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Improving the algorithm for selecting welding mode parameters under the impact of boundary conditions of the workpiece

A Yu Melnikov^{1,2}, M A Sholokhov^{1,2} and D S Buzorina^{1,2,*}

¹Federal State Autonomous Educational Institution of Higher Education “Ural Federal University named after the first President of Russia B.N. Yeltsin”, Ekaterinburg, Russia, 620002

²SHTORM Co.Ltd, Ekaterinburg, Russia, 620100

*Darja.buzorina@yandex.ru

Abstract. This article discusses the application of a mathematical model of heat transfer during welding to create an algorithm for choosing the welding mode parameters during programming of automatic welding systems. The results of the industrial implementation of a robotic welding system equipped with a developed algorithm for choosing a welding mode are presented.

1. Introduction

For now, due to its versatility and technological effectiveness, one of the most common welding methods is arc welding with a consumable electrode in shielding gases. However, despite the widespread use of this welding method, there is a problem of ensuring the constancy of the geometric dimensions of the weld and the mechanical properties of the joint along its entire length. The most unfavorable in terms of the appearance of defects are the initial and end parts of the weld, where according to production data up to 70% of defects appear. In these areas, the effects of the non-steady transfer of electrode metal (at the beginning of the weld) and the heat distribution at the end of the joint reveal themselves the most. It is known that during welding, when the heating source approaches the edge of the workpiece, the heat flow coming from the heating source is reflected from it, additionally heating the end part of the weld [1-3].

Due to the necessity to ensure the solution for the task with high accuracy in the zones of high temperatures and large temperature gradients near the weld pool, as well as the need to take into account the change in the thermophysical properties of the metal due to the temperature, the optimal numerical solution method, namely, the finite difference method. [4, 5]

The developed numerical model of heat distribution processes during welding with a consumable electrode in shielding gases takes into account the influence of temperature field distortion at the end of the joint due to heat reflection from the edge. As a target function, the temperature deviation at the boundary of the weld pool from the melting temperature was chosen, which thereby sets the condition: the constancy of the geometric parameters of the weld along its entire length. A similar approach was used to solve the optimization problem during welding of pipes of small diameters [6, 7].



Based on the developed mathematical model of heat transfer, a program for calculating the temperature during single-arc welding by the finite difference method based on the heat balance equations has been created.

Conducted computational experiment made it possible to obtain regression equations describing the length of the edge influence zone, accompanied by overheating of the metal, and the change in weld width during single-arc welding, depending on the thickness of the material being welded and the heat input [8].

These equations can be applied when programming the automatic welding mode.

2. Application of the developed algorithm in modern production

The developed algorithm for choosing the welding mode was used in the development and implementation of the technology of robotic welding of the exhaust manifold with catalytic converter. The workpiece is a stamped-welded structure of complex geometric shape made of 08Kh17T steel (analogy X3CrTi17 - DIN, Germany) according to GOST 5632-2014. It is used in the exhaust system of Lada cars for their cleaning from particles of heavy metals and other harmful substances.

The most safety critical parts in this workpiece are circular seams (Figure 1), connecting the nozzles to the catalytic converter housing. These welds should be pressure tight and have high mechanical properties to withstand the pressure of gases heated to high temperatures.

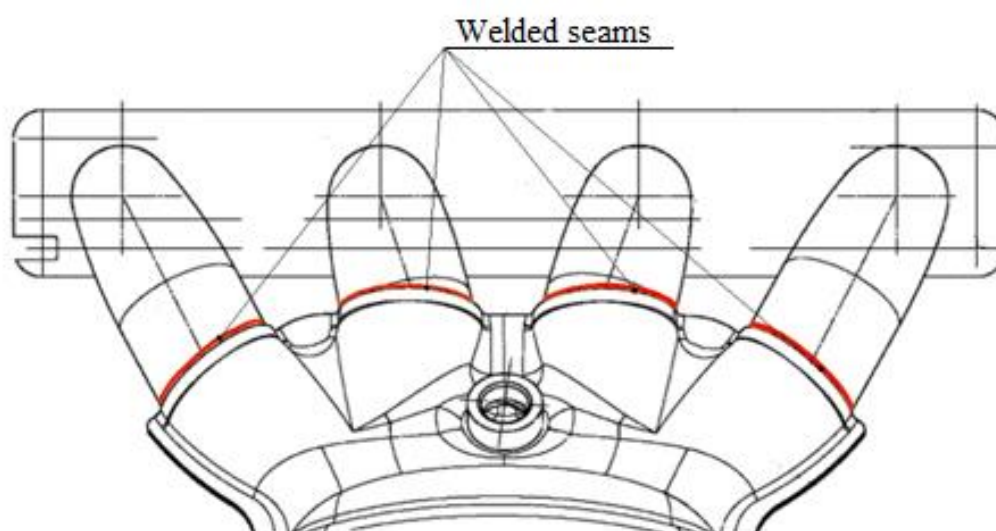


Figure 1. Circular seams of the nozzles with catalytic converter housing.

Welding technology should provide seams with the parameters shown in Figure 2.

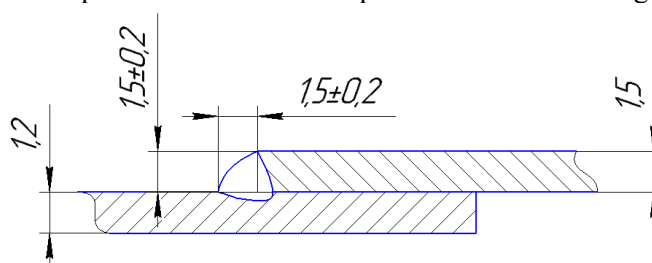


Figure 2. Weld parameters for nozzles and housing.

The main objective in introducing a new welding technology was to increase productivity, reduce the reject rate during welding by ensuring uniform distribution of heat along the entire length of the joint, including its beginning (ending) part. Factors affecting the distribution of heat along the length of the welded joint include the following:

- the wall thickness of the welded nozzles and the housing were 1.2 mm and 1.5 mm, respectively - this amplified effect of additional heating of the final part of the joint with heat from the beginning part of the seam;

- the presence of uneven gaps between the nozzle and the housing leads to an uneven distribution of heat and poor-quality formation of the seam. $\alpha\pi$

A distinctive feature of this task was that the design features of the workpiece (the receiving nozzle was made of two stamped halves) did not allow the entire seam to be made in one installation position, therefore, the circular seam was welded in two stages. Initially, the first half of the joint was welded, then the product was turned over 180 degrees and the second half of the joint was welded (Figure 3).

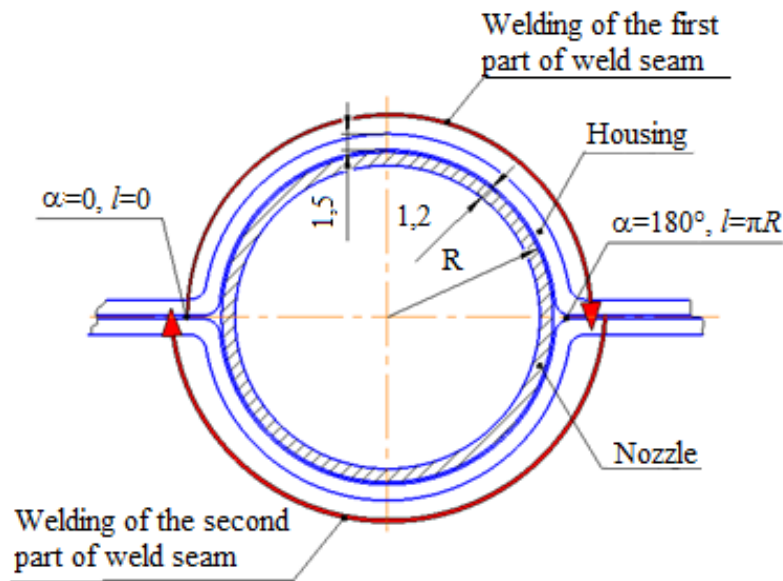


Figure 3. Schematic of the joint welding.

The basis for the development of welding technology was taken from the study [3]. Namely, when searching for a selection algorithm, it was assumed that the width of the seam along its entire length should remain constant - given value. In this regard, the condition was accepted that at a distance $A = e / 2$, where e is the weld width, the difference in the heating temperature and the melting temperature of the metal being welded ($T_e / 2 = T_{melt}$) should tend to a minimum, i.e., the difference between the calculated and accepted the melting temperature should not exceed the value of the calculation error.

After entering the data, the boundary position of the beginning of the influence of the reflected heat flow on the width of the seam is determined:

$$\Delta = e_{i+1}(x) - e_i(x) > norm \quad (1)$$

At the next step, a cyclic comparison of the actual seam width in each interval with a normalized value is performed:

$$\Delta_i = |e_i(x) - e_{norm}| > \Delta_{norm} \quad (2)$$

If the normalized value is exceeded, the linear energy of the process is adjusted:

$$q_{modi} = q_{const} \frac{e_{norm}}{e_i(x)} \quad (3)$$

At the end of the execution of the calculation cycles, an array of coordinate values and the corresponding arc powers $\Omega = \{x_i; Q_{\text{mod } i}\}$, on the basis of which the function of current and voltage control is formed:

$$\begin{cases} I = f(x) \\ U = f(x), \end{cases}$$

given that

$$q(x) = \frac{\eta \cdot I(x) \cdot U(x)}{V_{ce}}. \quad (4)$$

The obtained data array is transferred to the actuator, where a welding program is formed with the control system based on the function parameter selection function, in which the calculated values of I and U correspond to each x coordinate. The sequence of steps for the algorithm is shown in Figure 4.

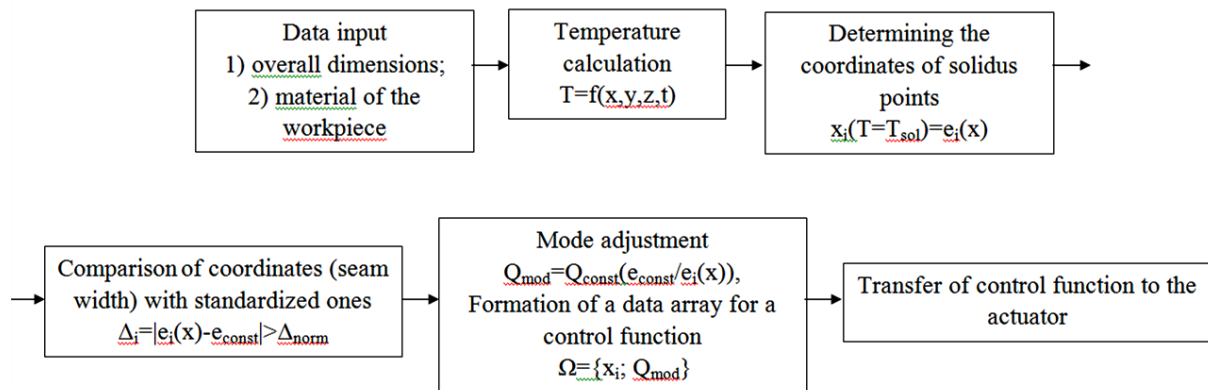


Figure 4. The sequence of steps for the algorithm of choosing the weld mode parameter

According to the developed model, the function of changing the process parameters (linear energy) was determined in accordance with the target function to ensure the specified weld dimensions (Figures 5-6).

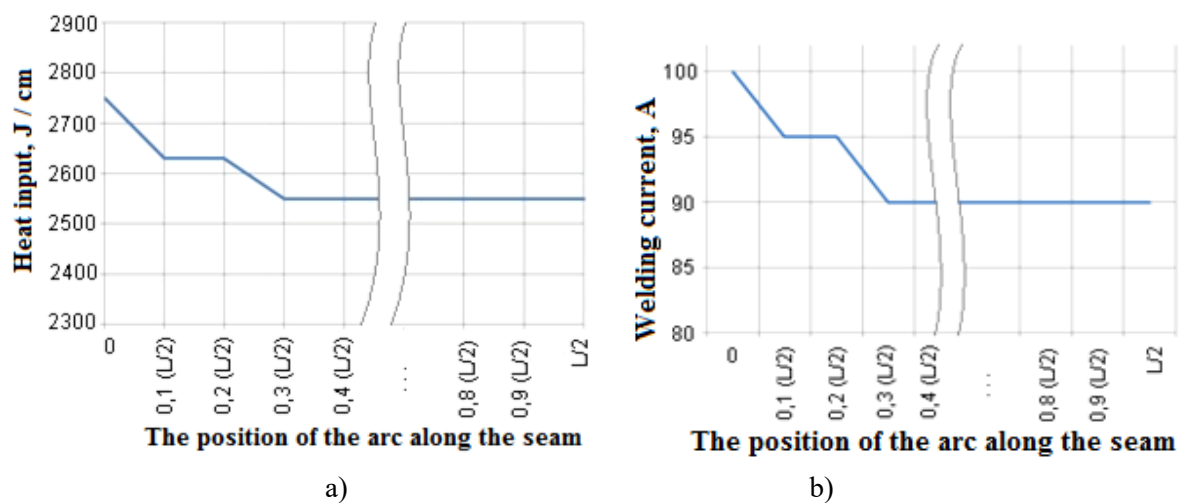


Figure 5. The distribution of the energy parameters of the arc along the length for the first half of the seam: a) linear energy; b) welding current (L - total weld length)

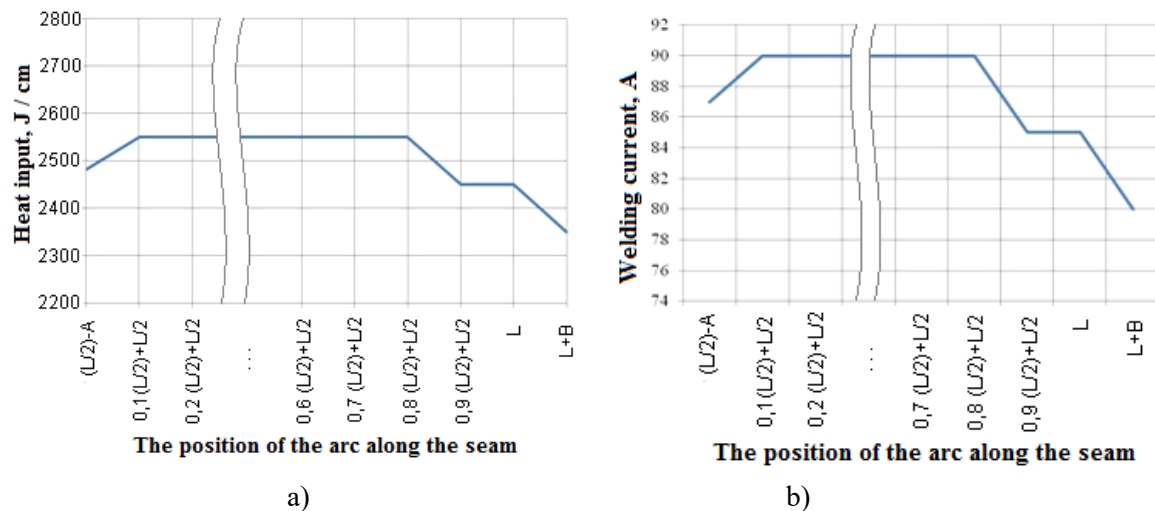


Figure 6. Distribution of energy parameters of the arc along the seam length for the second half of the seam: a) linear energy, b) welding current (L - total length of the seam, A, B - overlap of the seam)

From Figures 5-6 it follows that with the established distribution of the linear energy of the process along the length of the joint, the width of the seam should be constant. In return, if you do not apply the control of linear energy, but leave it constant, then the temperature at the beginning of the seam will be slightly lower, and in the end, higher than the melting temperature. We can conclude that at the beginning of the joint, the seam will be narrower (insufficient penetration or irregular shape of the seam is possible), and at the end it will be much wider, and with small thicknesses of the workpiece, an increase in temperature can lead to burning or also unsatisfactory formation.

The application of the function of changing the parameters of the welding process made it possible to ensure uniformity of the specified dimensions of the welds along its entire length (Figure 7).



Figure 7. Examples of welds of finished workpieces produced using the developed algorithm.

The introduction of this robotic welding system, equipped with an algorithm for choosing the welding mode, allowed to reduce the number of defects in the manufacture of workpieces from 20 to 3 % and increase welding productivity by 1.5 times, which is confirmed by the acceptance protocol.

3. Conclusions

1. Based on the simulation results, an algorithm for choosing the welding mode was developed and the areas of its effective application for low alloy steels with a thickness of welded parts from 2 to 14 mm

were determined. Application of the algorithm made it possible to ensure the stability of the geometric dimensions of the weld along the entire length of the welded joint and to improve its quality.

2. Industrial implementation of the developed algorithm in welding robotic systems allowed to reduce the proportion of defective goods during single-arc welding up to 3 %, increase productivity by 50 %.

Acknowledgement

The assistance provided by the translator of the present article Ms. Natalia Karamysheva was greatly appreciated.

References

- [1] Korolev N V 1996 *Raschety teplovykh protsessov pri svarke, naplavke i termicheskoy rezke: Uchebnoye posobiye. [Numerical calculations of thermal processes in welding, surfacing and thermal cutting: Textbook]* (Yekaterinburg: USTU) p 156
- [2] Karkhin V A 2015 *Teplovyye protsessy pri svarke. 2-ye izd., Pererab. i dop. [Thermal processes in welding. 2nd ed., revised and enlarged.]* (St. Petersburg: Polytechnic University Press) p 572
- [3] Melnikov A Yu 2019 *Obespecheniye normativnykh razmerov svarnogo potoka v oblasti vliyaniya teplovogo potoka na osnove resheniya teplovoy zadachi: dis. ... Kand. tekhn. nauk. [Ensuring the standard dimensions of the weld in the influence area of the reflected heat flow based on the thermal solution : Extended Abstract of Cand. Sci. (Techn.) Dissertation]* (Moscow) p 155
- [4] Berezovskiy B M 2002 *Matematicheskiye modeli dugovoy svarki. T. 1. Matematicheskoye modelirovaniye i informatsionnyye tekhnologii, modeli svarochnoy vannы i formirovaniye shva [Mathematical models of arc welding. B 1. Mathematical modeling and information technology, types of the weld pool and the weld seam formation]* (Chelyabinsk: South Ural State University Press) p 585
- [5] Galanin M P, Savenkov E B 2017 *Metody chislennogo analiza matematicheskikh modeley [Methods of numerical analysis of mathematical models]* (Moscow: BMSTU Press) p 591
- [6] Kohdo K, Ueda K and Oji T 1998 Optimum heat input control in girth welding of small diameter pipe *Welding International* Vol 12 **6** P 440-447
- [7] Kohdo K, Ueda K and Oji T 1998 Algorithm based on non-linear programming method for optimum heat input control in arc welding *Science and Technology of welding and Joining* Vol 3 **3** P 127-134
- [8] Sholokhov M A, Melnikov A Yu and Buzorina D S 2020 Obespecheniye kachestva svarnykh soyedineniy posredstvom algoritma vybora rezhima pri robotizirovannoy svarke [Weld quality assurance through the use of the selection algorithm of mode parameters during robotic welding] *Сварка и диагностика [Welding and diagnostics]* **2** P 57-60